

Hand wrist cumulative trauma disorders in industry

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ABSTRACT A total of 574 active workers from six different industrial sites were categorised into four force repetitive exposure groups. Workers in low force-low repetitive jobs served as an internal comparison population for the three other groups. Videotapes and surface electromyography were used to estimate hand force and repetitiveness. The presence of cumulative trauma disorders (CTD) was determined by structured interview and standardised non-invasive physical examination. Only workers who had been working on the study jobs for at least one year at the time of evaluation were eligible for selection. Categorisation of jobs and identification of CTDs were carried out independently by investigators who were appropriately blinded to exposure and outcome. The analysis of associations between CTDs and exposure categories were performed using Mantel-Haenszel plant adjusted odds ratios and unconditional multiple logistic regression. Significant positive associations were observed between hand wrist CTDs and high force-high repetitive jobs. These associations were independent of age, sex, years on the specific job, and plant.

Repetitive, sustained, or forceful motions occurring over time may compromise the integrity or functioning of the soft tissues producing inflammation of the tendons or compression of the peripheral nerves¹⁻⁵ leading to a group of cumulative trauma disorders (CTDs). These disorders have also been referred to as "repetitive strain injuries",⁶ "over use syndromes,"⁷ or "repetitive motion injuries."⁸

Using standardised questionnaires and screening examinations,⁹ the estimated prevalence of tendon related disorders of the hand and wrist ranged between 18% among Swedish scissor making workers to 56% among Swedish packers^{10 11}; the prevalence of carpal tunnel syndrome among Finnish butchers was 53%.¹²

It has been suggested that two major occupational risk factors for hand wrist CTDs include repetitiveness and forceful exertions.^{5 13} There have been few epidemiological investigations of the incidence or prevalence of hand and wrist CTDs in United States industry and the main objective of this cross sectional investigation was to determine if forceful and repetitive job attributes were positively associated with CTDs of the hand and wrist.

Materials and methods

A total of 574 active workers from six different industrial plants were categorised into four exposure groups:

Low force-low repetitive (LOF.LOR)

High force-low repetitive (HIF.LOR)

Low force-high repetitive (LOF.HIR)

High force-high repetitive (HIF.HIR)

Workers in the LOF.LOR jobs served as an internal comparison population for the three other groups.

The six plants that participated in the study included electronics assembly, major appliance manufacturing, investment casting of turbine engine blades, apparel sewing, ductile iron foundry, and bearing manufacturing.

JOB SELECTION

All the jobs with at least 20 workers were identified and reviewed on plant walkthroughs by investigators (blinded to worker health problems) who observed representative workers and estimated cycle time, production rates, and weight of parts handled. If the work cycle had a sequence of steps that repeated themselves within the cycle this was defined as a "fundamental cycle." *High repetitive* jobs were defined as

those with a cycle time of less than 30 seconds or more than 50% of the cycle time involved performing the same type of fundamental cycles. *Low repetitive* jobs were those with a cycle time of more than 30 seconds and less than 50% of the cycle time involved performing the same type of fundamental cycles. *High force* jobs were those with estimated average hand force requirements of more than 4 kg and *low force* jobs were those with estimated average hand force requirements below 1 kg.

JOB ANALYSIS

The jobs chosen on the basis of initial walkthrough classifications were analysed in greater detail to verify their walkthrough classification. At least three representative workers in each selected job were videotaped (using two cameras) performing the job for at least three cycles. Playback of the videotape in slow motion allowed a more detailed estimation of the number and percentage of cycle time spent in fundamental cycles to characterise repetitiveness.

Bilateral surface electromyographic (EMG) recordings (incorporated into the video mixer system) from the forearm flexor muscles were used to estimate hand force requirements of the job. All EMGs were calibrated to known forces before and after the subject was filmed.¹⁴ This information was abstracted from the video system about every 20th frame (1/3 second). Mean force and standard deviation for the right and left hand were estimated and averaged over subjects performing the same job.

To characterise the force requirements of different types of jobs, a weighting measure was used to take into account extreme variability in force within the cycle. This was referred to as "adjusted force" = (variance/mean force) + mean force. An adjusted force (either right or left hand) cutoff of 6 kg was used to differentiate "high" from "low" force. This cutoff was selected both to minimise the initial walkthrough misclassification and to result in more homogeneous groups. The mean adjusted force for the low force jobs was 3.0 ± 1.6 kg and for the high force jobs, 12.7 ± 8.6 kg.

Eight of the 34 jobs changed exposure categories from the initial walkthrough classification; three changed repetitiveness categories and five changed force categories. No LOF.LOR jobs became HIF.HIR jobs or vice versa.

SUBJECT SELECTION AND CTD IDENTIFICATION

A random sample of 12–20 active workers per job, stratified by age and sex where possible, was selected from among those with at least one year's seniority on the study job. Prior selection of workers (whether by employer or employee) into jobs, particularly with respect to sex, mitigated against equal distributions of

men and women in many jobs.

Structured interviews and screening physical examination were used to evaluate the health status of all subjects.¹⁵ All the health evaluations were conducted in private rooms in the plants during work hours by University of Michigan personnel (blinded to exposure status).

Interview data elicited demographic, prior health and work history information including years on the job, prior hand wrist injuries, chronic diseases, reproductive status of women and recreational activities. The remaining questions asked about hand wrist pain or discomfort experienced in the previous two years. If the subject had experienced recurring difficulty in one or more parts of the hand and wrist, more detailed information was sought regarding the subject's complaints including location, duration, onset, aggravating factors, and treatment.

All the subjects received a standardised physical examination from a research team examiner blinded to medical history and exposure. It included inspection and palpation; active, passive, and resisted range of motion testing; palpation of pulses; deep tendon reflexes; and dermatome evaluation. Endpoints included tendon related disorders (tendinitis, tenosynovitis, de Quervain's disease, trigger finger) and peripheral nerve entrapments (carpal tunnel syndrome, Guyon tunnel syndrome, digital neuritis). Localised osteoarthritis of the interphalangeal joints (morning stiffness, Heberden's nodes, decreased passive range of motion) were not included as hand wrist CTDs. A non-specific designation was used if no clear pattern was present on physical examination. General criteria were defined to classify positive CTDs for the purpose of this investigation (table 1).

STATISTICAL ANALYSES

To test the hypothesis of no association between exposure and hand wrist CTDs, two basic approaches were used, contingency analysis and multiple logistic regression.

Throughout the analyses, sex was considered a potentially important confounder or effect modifier. To test the hypothesis of no association between sex and CTDs, job adjusted odds ratios (Mantel-

Table 1 General criteria for cumulative trauma disorders

Interview:
Symptoms of pain, numbness, or tingling
Symptoms lasting more than 1 week or more than 20 times in the previous year, or both
No evidence of acute traumatic onset
No related systemic diseases
Onset since working on current job
Physical examination:
Characteristic signs of muscle, tendon, or peripheral nerve lesions
Rule out other conditions with referred symptoms

Table 2 Plant combined age and years on the job by exposure group

	Exposure group			
	LOF.LOR	HIF.LOR	LOF.HIR	HIF.HIR
Age (SD):				
Men	39.3 (10.4)	40.2 (10.0)	41.3 (9.8)	36.2 (8.7)
Women	39.8 (10.7)	37.6 (7.9)	40.4 (11.4)	38.8 (9.7)
Years on job (SD):				
Men	6.6 (4.7)	9.5 (6.6)	8.3 (6.8)	8.6 (6.2)
Women	8.0 (5.8)	5.8 (3.6)	8.0 (5.6)	7.5 (5.4)

LOF.LOR = Low force-low repetitive.

LOF.HIR = Low force-high repetitive.

HIF.LOR = High force-low repetitive.

HIF.HIR = High force-high repetitive.

Haenszel) were calculated for women compared with men for those jobs where there were cases and both sexes represented.^{16,17} Plant adjusted odds ratios (Mantel-Haenszel) were used to estimate associations between exposure and CTDs while controlling for a potential "plant effect." Unconditional multiple logistic regression techniques¹⁷ were used to estimate associations between CTDs and exposure (three 0,1 variables for HIF.LOR, LOF.HIR, and HIF.HIR) while controlling for age and years on the job (continuous variables), sex (0,1 variable), and plant (five 0,1 variables). First and second level interaction terms were also entered into the model.

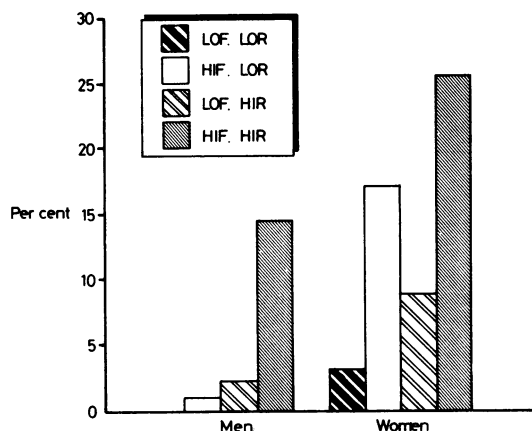
Results

STUDY POPULATION CHARACTERISTICS

Of the 641 eligible workers originally selected from employee rosters, 574 (90%) were included in the final study population (2% refused to participate, 3.3% were on medical leave of absence, 4.2% did not meet selection criteria, and 1% were excluded owing to active rheumatoid arthritis). Overall, there were no differences between men and women with respect to age or years worked on the job (table 2). There were,

however, significant differences in age and years on the job by plant sex exposure strata ($p < 0.001$).

Men and women were not evenly distributed in exposure categories. Men tended to predominate in the HIF.LOR category and women in the LOF.HIR category (table 3). Within exposure categories men and women often did not perform the same jobs. Both men and women were in 17 of the 34 jobs selected.



Prevalence of hand wrist cumulative trauma disorders on interview and physical examination by exposure group and sex (plants combined)

Table 4 Types of hand wrist CTDs identified

Tendon related disorders*	29
Carpal tunnel syndrome	7
Tendon related and carpal tunnel syndrome	5
Guyon tunnel syndrome	3
Digital neuritis	4
Raynaud's phenomenon	1
Non-specific pain	2
Total	51

*Tendinitis, tenosynovitis, de Quervain's disease.

Table 3 Sex distribution by plant and exposure group

Plant	Exposure group							
	LOF.LOR		HIF.LOR		LOF.HIR		HIF.HIR	
	Men	Women	Men	Women	Men	Women	Men	Women
1	1	11	17	19	6	29	5	7
2	21	—	22	—	11	1	11	18
3	12	27	6	32	12	50	13	—
4	2	16	13	1	—	20	—	21
5	18	—	21	—	14	—	39	10
6	21	7	22	—	—	—	—	18
Total	75	61	101	52	43	100	68	74
Per cent	26.1	21.3	35.2	18.1	15.0	34.8	23.7	25.6

LOF.LOR, LOF.HIR, HIF.LOR, HIF.HIR see table 2.

Table 5 Prevalence of hand wrist CTDs by plant,* physical examination, and interview

Plant	Total	No (%) of CTDs
Plant 1	95	6 (6.3)
Plant 2	84	9 (10.7)
Plant 3	152	19 (12.5)
Plant 4	73	3 (4.1)
Plant 5	102	9 (8.8)
Plant 6	68	5 (7.4)
Total	574	51 (8.9)

*Table 1 describes criteria for positive CTDs.

There were no significant differences in reported health history or recreational activities between sex exposure groups.

HAND WRIST CUMULATIVE TRAUMA DISORDERS

There were 105 subjects (18.3%) with hand wrist CTDs in the previous year on interview (11.1% men, 25.4% women) and 51 (8.9%) with these disorders on physical examination and interview (4.2% men, 13.6% women, $p < 0.0001$) (fig, table 4). When women were compared with men in jobs where there

Table 6 Hand wrist CTDs on physical examination and interview by exposure group. Crude and plant adjusted odds ratios (OR)

	Exposure group			
	LOF.LOR	HIF.LOR	LOF.HIR	HIF.HIR
Men:				
Yes	0	1	1	10
No	75	100	42	58
Crude OR	1.0	2.3	5.3	27.1†
Plant adjusted OR	1.0	2.7	3.3	4.9*
Women:				
Yes	2	9	9	19
No	59	43	91	55
Crude OR	1.0	6.2*	2.9	10.2†
Plant adjusted OR	1.0	4.1	2.9	5.2
Sex combined:				
Yes	2	10	10	29
No	130	134	133	113
Crude OR	1.0	4.7*	5.0*	17.2†
Plant adjusted OR	1.0	4.9*	3.6	30.3‡

Chi square * $p < 0.05$; † $p < 0.001$; ‡ $p < 0.0001$.

LOF.LOR, LOF.HIR, HIF.LOR, HIF.HIR see table 2.

Table 7 Predictors of hand wrist CTDs.* Multiple logistic regression analysis ($n = 574$)

Predictor	Model I		Model II	
	Coefficient (SE)	Odds ratio	Coefficient (SE)	Odds ratio
Sex (F:M)	1.9644 (0.41998)	7.1	1.5781 (0.41195)	4.8
Age	- 0.00875 (0.01788)	1.0	- 0.00856 (0.01899)	1.0
Years job	0.00530 (0.03089)	1.0	- 0.00787 (0.03272)	1.0
Plant 2	1.5328 (0.60155)	4.6	0.28542 (0.43788)	1.3
Plant 3	0.78980 (0.50973)	2.2	1.14910 (0.52993)	3.2
Plant 4	- 0.57319 (0.73374)	0.6	- 1.18930 (0.78834)	0.3
Plant 5	1.6485 (0.62570)	5.2	0.31522 (0.65790)	1.4
Plant 6	0.71800 (0.64958)	2.1	- 0.32108 (0.73792)	0.7
HIF.LOR			1.6487 (0.80129)	5.2
LOF.HIR			1.1994 (0.79897)	3.3
HIF.HIR			3.3713 (0.81109)	29.1
- 2 Log likelihood	311.98		278.40	

Statistically significant predictors ($p < 0.05$): sex, plant, exposure.

*Positive CTD criteria see table 1.

HIF.LOR, LOF.HIR, HIF.HIR see table 2.

were cases of hand wrist CTDs (10 jobs), the "job adjusted" odds ratio (Mantel-Haenszel) for women was 3.1 on physical examination and interview ($p < 0.05$). There were no statistically significant age group trends observed for either men or women. No statistically significant difference between plants was observed (table 5).

Plant adjusted odds ratios indicated an increased risk for hand wrist CTDs in all exposure groups compared with the LOF.LOR group, although this increase was not always statistically significant, and in men based on small numbers for the HIF.LOR and LOF.HIR groups (table 6). The risk for HIF.HIR men was five times that of the LOF.LOR group ($p < 0.05$). In the sex combined analysis the odds ratio was 30.3 ($p < 0.0001$) for the HIF.HIR group. The difference between the combined and sex specific odds ratios was due to including women from two jobs in the combined analysis that were not included in the female specific analysis due to no female controls in these two plants. These jobs had a high prevalence of CTDs among women (44.4% and 30% respectively).

The predictors in the logistic regression analysis (table 7) were similar to the odds ratios observed in the sex combined stratified analysis. The predicted association between sex and CTDs (odds ratio = 4.8) did not take into account job differences between men and women within exposure categories. When *force* (low, high), irrespective of repetitiveness, was entered into the model as the only exposure measure, the odds ratio for high force was 4.4 ($p < 0.0001$). When *repetitiveness* (low, high), irrespective of force, was entered into the model as the only exposure variable, the odds ratio was 2.8 ($p < 0.005$).

Discussion

High force and high repetitiveness were generally positively associated with hand wrist CTDs. Irrespective of other factors, the combination of high force and high repetitiveness (HIF.HIR) substantially increased the magnitude of association more than either factor alone.

The effect of sex as a confounder could not be adequately estimated because men and women within exposure groups were not always performing the same job. Even when they were performing the same job, women tended to be at greater risk for some, but not all, hand wrist CTDs. For example, the job adjusted odds ratio for carpal tunnel syndrome was 0.6 (women to men) and not statistically significant whereas for tendon related CTDs, the job adjusted ratio for women was 4.3 ($p < 0.5$). Possibly these observed associations between women and CTDs were actually a function of unmeasured job attributes. For example, wrist postures required on a job

are often determined by the height of the work station with respect to the location of the worker. A tall man may use less wrist flexion or ulnar deviation than a woman (or shorter man) in performing the same job. In this example what may be assumed to be a sex difference would in reality be a difference in working posture. To test this hypothesis the job of each worker in a job would have to have been videotaped and analysed. This was not done in this investigation.

The classification of jobs into exposure categories was based on combined summary estimates for three "representative" workers. Within some jobs, there was considerable variability between the three workers and their job requirements, particularly with respect to posture. This was more often the case with low repetitive jobs than high repetitive jobs. Individuals performing the same job may have actually belonged in different exposure categories. Usually the effect of exposure misclassification would be to decrease differences between exposure groups and decrease the magnitude of associations with CTDs. It is unlikely that individual variation would cause sufficient misclassification to cause changes between LOF.LOR and HIF.HIR categories. Of those jobs which changed exposure categories between initial walkthrough and final classification, there was no transfer of jobs from LOF.LOR to HIF.HIR or vice versa.

Awkward postures (wrist deviation, flexion, hyperextension, and finger pinching) are risk factors for hand wrist CTDs^{4,5,13} that were not controlled for in this investigation. Possibly those in HIF.HIR jobs actually had more awkward postures than those in other categories. A preliminary review of postures on the video tapes suggests that the difference in the prevalence of CTDs in jobs within the same exposure category may be explained by differences in awkward postures. This hypothesis requires further investigation.

Several blinding measures were used to minimise observer bias in the selection of jobs and in the CTD screening evaluations. Even with these precautions, some observer bias may have been present. It was occasionally difficult to keep subjects from talking about their jobs until the end of the interview or examination. Observer bias would probably have led to an overestimation of the associations reported. It is also possible that some workers may have minimised or exaggerated their symptoms based on preconceptions of how their jobs were affecting their health. Exaggeration in the "exposed" groups would have resulted in overestimation of associations. Estimates of job satisfaction were not included in this investigation.

The findings in this investigation are consistent with Scandinavian studies,^{10,11,18} using similar

screening methods. In this study the overall prevalence of hand wrist CTDs on physical examination and interview was 13.6% among women. This is somewhat lower than the 18% reported by Kourinka and Koskinen¹⁰ among women in a scissor making factory. These findings were also lower than those reported by Luopajarvi *et al*¹¹; 56% of hand wrist disorders among female packers (probably a HIF.HIR job) compared with 14% among shop assistants (probably a LOF.LOR job). The range for women in this investigation, however, was from 3.3% among LOF.LOR women to 25.7% among HIF.HIR women. Within certain HIF.HIR jobs the prevalence was as high as 44.4%. Viikari-Juntura reported a 4.4% overall prevalence of tendinitis among slaughterhouse workers (not stratified by exposure) similar to the overall 5.1% identified in this investigation (range from 0.7% in LOF.LOR to 12.0% in HIF.HIR).¹⁸ He suggested that the relatively low prevalence of disorders found in the slaughterhouse workers may be explained by a high selection/survivor effect.

The findings in this investigation may also have underestimated the prevalence of hand wrist CTDs in several ways. Firstly, subject selection was limited to active workers. Those away from the job with CTDs at the time of evaluation (potentially more severe cases) would not have been available for study. Secondly, the one year seniority criteria for subject selection excluded those who might have had CTDs and transferred before one year as well as those with CTDs but not on the job for at least one year. The finding that hand wrist CTDs were negatively associated with age and years on the job (table 6) supports the argument of selection/survival bias in the study population.

Our findings may help in directing workplace interventions in the worker exposure disease cycle because they suggest a strategy for primary prevention. Through job modification a reduction in force or repetitiveness may result in a reduction in the prevalence of CTDs.

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manual by Silverstein and Fine is available from the University of Michigan, School of Public Health Department of Environmental and Industrial Health.

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